The ATLAS Forward Proton Programme

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on behalf of
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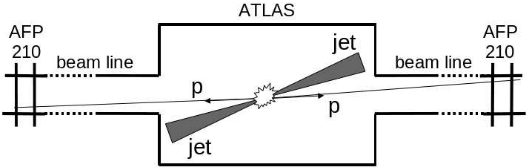
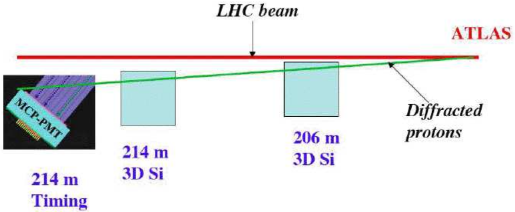
Introduction

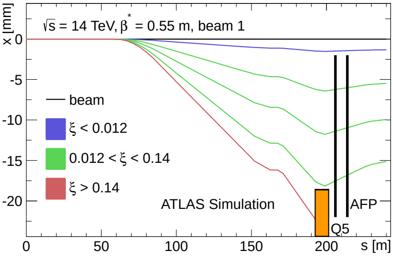
- **Motivation**: detect intact protons from hard interaction scattered at very small angles (into the LHC beam pipe).
- Detector located close to the beam (Movable Beam Pipe).
- Protons must leave beam envelope.

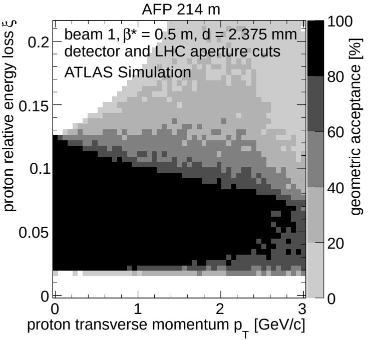




- Proton position measurement (3-D Pixel detectors).
- Precise time of flight measurement (QUARTIC timing detector).

AFP Acceptance



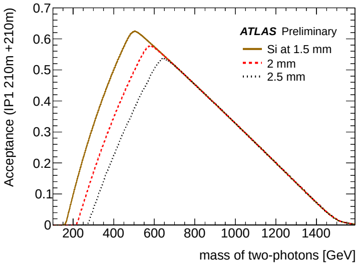


$$M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$$

$\xi_1, \ \xi_2$ – proton relative energy loss

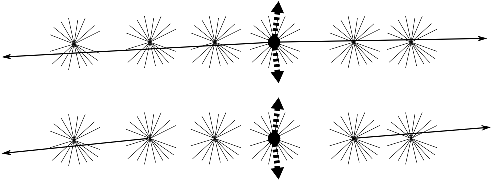
$$\xi = (E_{beam} - E_{proton})/E_{beam}$$

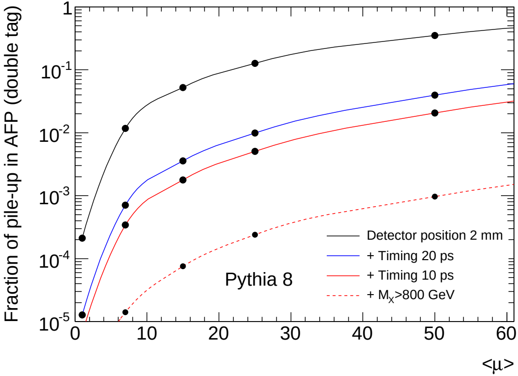
$$200\,GeV < M_X < 2000\,GeV$$



Pile-up

Minimum bias pile-up protons may fake hard diffractive signature.





Physics Processes

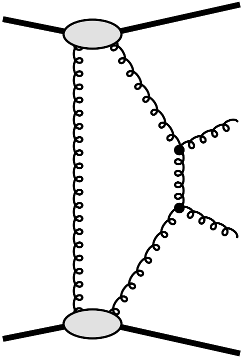
AFP detectors will give a possibility to extend ATLAS Physics Programme by studies of:

- QCD studies:
  - hard single diffraction (*eg.* jets, W/Z),
  - hard central diffraction (*eg.* DPE jets, DPE W/Z),
  - central exclusive production (*eg.*, jets, $\gamma\gamma$),
- exploratory physics:
  - anomalous quartic gauge couplings ($\gamma,\ W,\ Z$):
    - effective approach for testing BSM,
    - extra dimensions, higgsless models,
  - SUSY,
  - magnetic monopoles.

Exclusive Jet Production

Exclusive Jet Production

Signature: two jets in central region + two intact protons
+ gap in rapidity between jet and proton (no remnants).



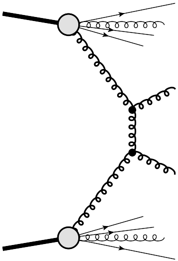
Exclusive Production

- Theoretical description – KMR model.
- No Pomeron remnants.
- Measurement constrain theoretical models.
- Limits on exclusive Higgs production.

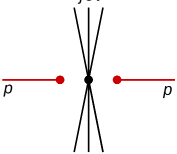
Very challenging measurement – all potential that AFP offers have to be used.

Background

Non-diffractive jets + pile-up.

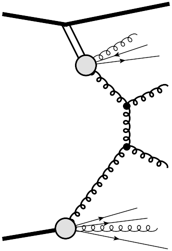


Non−difftactive Production

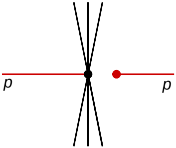


CS ($p_T > 150$ GeV):
645 nb

Single-diffractive jets + pile-up.

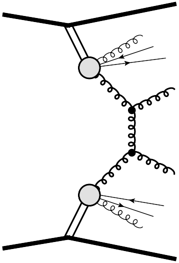


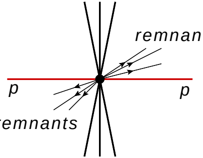
Single Diffractive Production



CS ($p_T > 150$ GeV):
2.26 nb

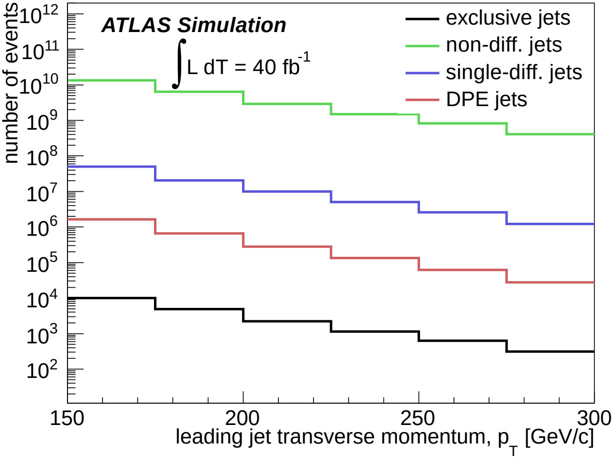
DPE jets.



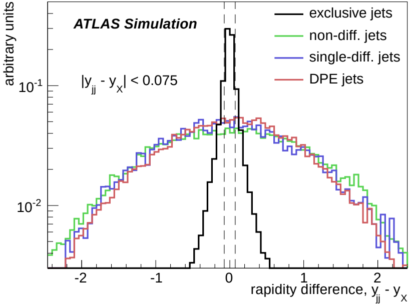


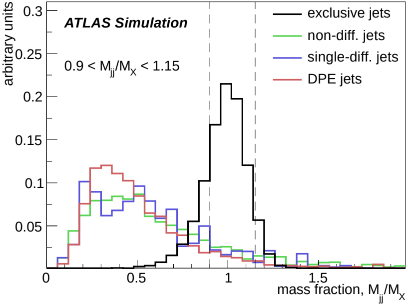
CS ($p_T > 150$ GeV):
40 pb

Initial Cross-Section



Six orders of magnitude to gain!





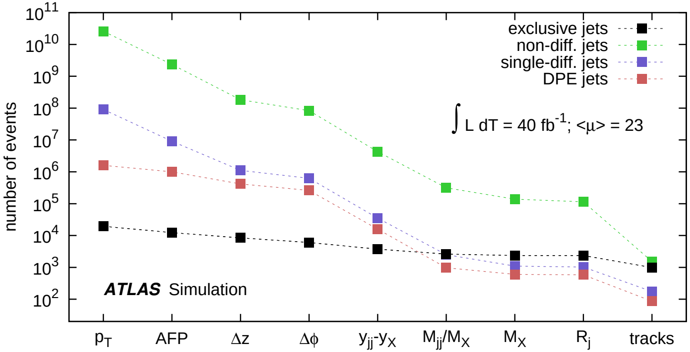
Difference, $y_{jj} - y_X$, of the rapidity of the jet system (y_{jj}) and the rapidity of the proton system $y_X = 0.5 \cdot \ln\left(\frac{\xi_1}{\xi_2}\right)$

Ratio of the jet system mass to the missing mass $M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$

Discriminating Power

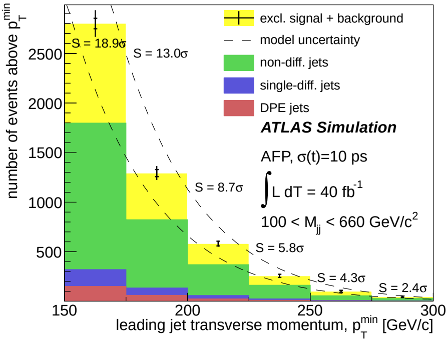
Additional selection:

- At least one proton tagged in each AFP station.
- Number of tracks outside the jet system < 4.
- Angle between two leading jets $2.9 < \Delta\phi < 3.3$.
- Missing mass $M_x < 550$ GeV/c^2.
- The distance between hard vertex reconstructed by ATLAS and from the AFP time measurement $|\Delta z| < 3.5$ mm;

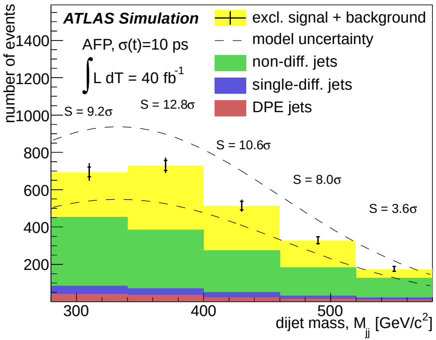


Final signal/background ratio $\approx$ 2/3 !

Number of Events ($<\mu>= 23$)



leading jet transverse momentum distribution above a given threshold



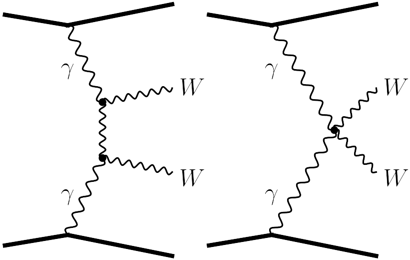
mass of the jet system distribution

Improvement of uncertainties coming from the Tevatron CDF measurements by about one order of magnitude!

Anomalous Couplings

Anomalous Couplings

Motivation: provide stringent test of the electroweak symmetry breaking mechanism.



Additional contribution from BSM Largangian:

$$\mathcal{L}_{\text{eff}}^{\text{BSM}} = - \frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta)$$
$$- \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

E. Chapon, O. Kepka, C. Royon, Phys. Rev. **D81** (2010) 074003

Signal and Backgrounds

Signal: QED *WW* SM, with a QGC.
W's decays leptonically (but semi-hadronic decays are also promising).

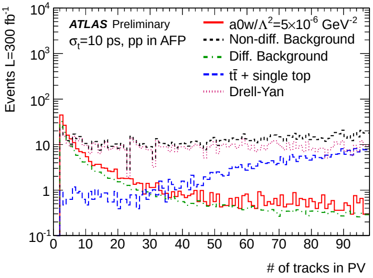
Backgrounds:

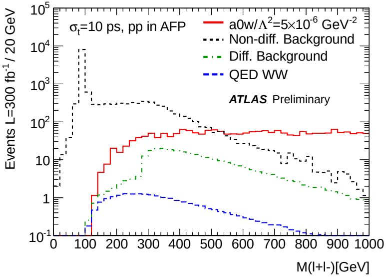
- non-diffractive (+ pile-up):
  - *WW*,
  - *WZ*,
  - *ZZ*,
  - Drell-Yan,
  - W/Z + jet,
  - *ttbar*,
  - single top.
- diffractive:
  - QED *ll*,
  - SD *WW*,
  - DPE *WW*,
  - DPE *ll*,

Generators: FPMC, Herwig++, Pythia.

Selection Cuts

- AFP acceptance $0.014 < \xi < 0.2$,
- leading lepton $p_T > 300$ GeV, sub-leading lepton $p_T > 20$ GeV,
- $M_{ll} > 300$ GeV,
- number of tracks from hard vertex < 3,
- $\Delta\phi_{ll} < 3.1$ rad,
- **$\mathbf{M_X} > 800$ GeV**.





Limits

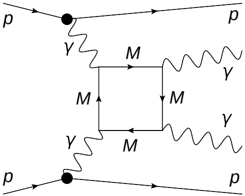
- the measurement of couplings at the highest luminosities is possible,
- precision of $\sim 10^{-6}$ GeV^{-2} where the BSM effect are expected:

	a_0^W/Λ^2 Sensitivity	
	5σ	95% C.L.
$\mathscr{L} = 40\ fb^{-1}, \mu = 23$	$5.5\ 10^{-6}$	$2.4\ 10^{-6}$
$\mathscr{L} = 300\ fb^{-1}, \mu = 46$	$3.2\ 10^{-6}$	$1.3\ 10^{-6}$

Additional topics

Additional topics

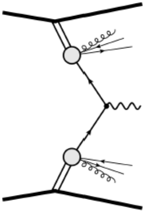
- **Main idea:** production of objects in which background can be extremely reduced by kinematical constraints coming from AFP proton measurements (high mass),
- Many new anomalous couplings to be studied if Higgs boson exists – new dimension 8 operators appearing leading to anomalous production of WW, ZZ, $\gamma\gamma$,
- Production of magnetic monopoles:



- SUSY sparticle production: precise mass measurement,
- Any production of new objects (with mass up to 2 TeV) via photon or gluon exchanges: KK resonances, black holes, *etc.*
- Other topics (special runs): jet-gap-jet in diffraction (tests of BFKL dynamics) – see talk by Christophe Royon, diffraction mechanism, Pomeron structure.

W Asymmetries

Test different diffraction mechanisms. Probe Pomeron structure.

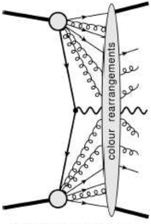


Quarks from Pomeron
Charge and flavour symmetry:
u=d=s=ubar=dbar=sbar

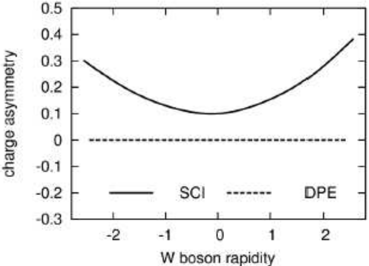
$$A = \frac{N_+ - N_-}{N_+ + N_-}$$

DPE: A = 0
SCI: A = 0.14

K. GolecBiernat, C. Royon,
L. Schoeffel, R. Staszewski,
Phys. Rev. **D84** (2011) 114006



Quarks from protons
Diffractive signature due to colour rearrangements



Summary

- Quartic anomalous couplings measurement at $\mu = 46$ and a total luminosity of 300 fb^{-1} is possible.
  The full AFP simulation in presence of pile-up confirms the gain in sensitivity between one and two orders of magnitude with respect to the standard (non-AFP) ATLAS methods.
  The use of the AFP allows reaching the values expected in Higgs-less or extra-dimension models.
- The production of exclusive dijet for $\mu = 23$ and a total luminosity of 40 fb^{-1} the measurement is possible and interesting due to the huge model uncertainties at present level of the theory understanding.
- For all physics cases, AFP capabilities in terms of proton tagging and timing resolution are key and unique features unprecedented sensitivity to quartic anomalous coupling or novel QCD measurements.